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Subduction Boundary

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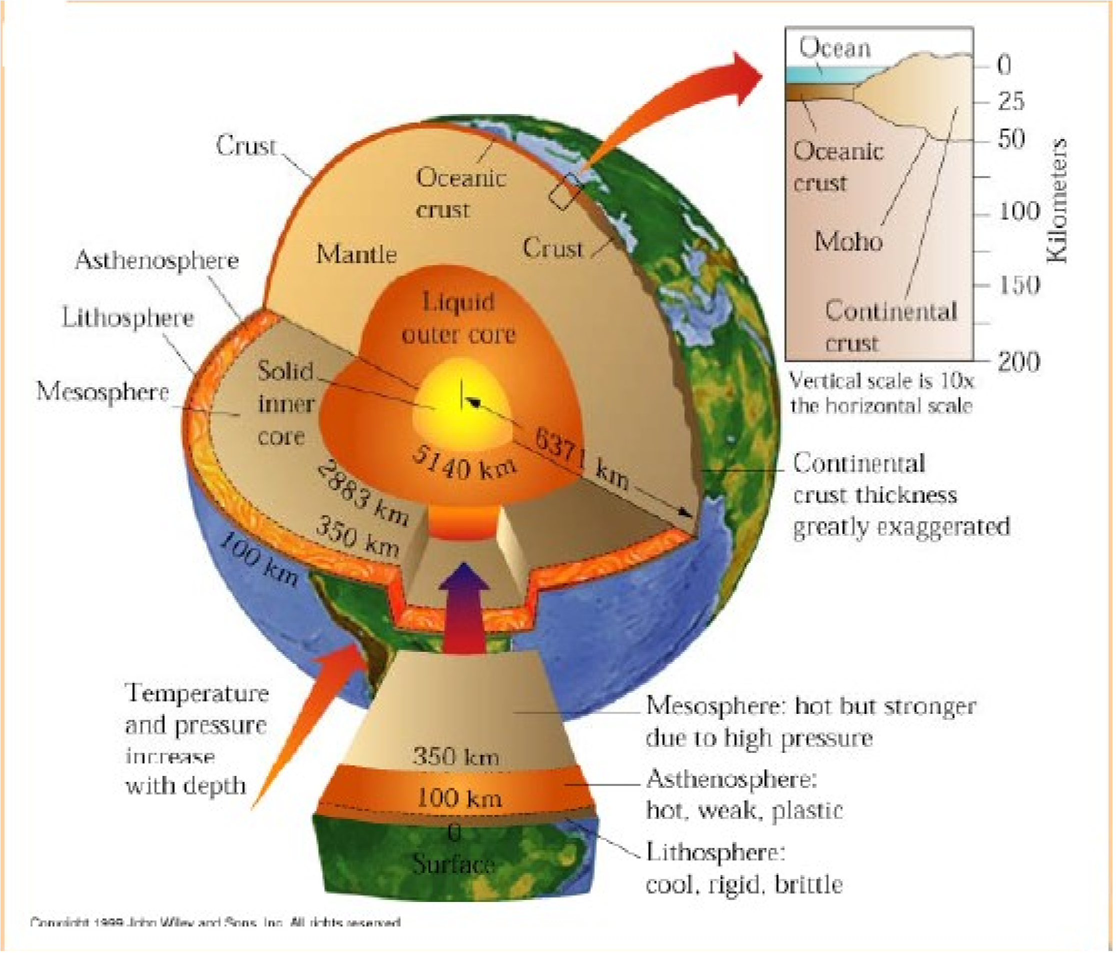
Introduction

Four billion six hundred million years ago the Earth is born from a cloud of dust and fire orbiting the sun. In the beginning there are no seas upon the barren Earth. The sun blisters down as poisonous gases swirl about. Racked with volcanoes, bombarded by asteroids and comets, Earth is incredibly hot with a sea of molten rock covering its surface. The early Earth is a world in slow turmoil for many, many thousands of years.


Ocean
0
25
50
100
150
200
Kilometers
Oceanic crust
Moho
Continental crust
Vertical scale is 10x the horizontal scale
Crust
Oceanic crust
Asthenosphere
Mantle
Crust
Lithosphere
Liquid outer core
Mesosphere
Solid inner core
6371 km
5140 km
2883 km
350 km
100 km
Continental crust thickness greatly exaggerated
Temperature and pressure increase with depth
350 km
100 km
0
Surface
Mesosphere: hot but stronger due to high pressure
Asthenosphere: hot, weak, plastic
Lithosphere: cool, rigid, brittle

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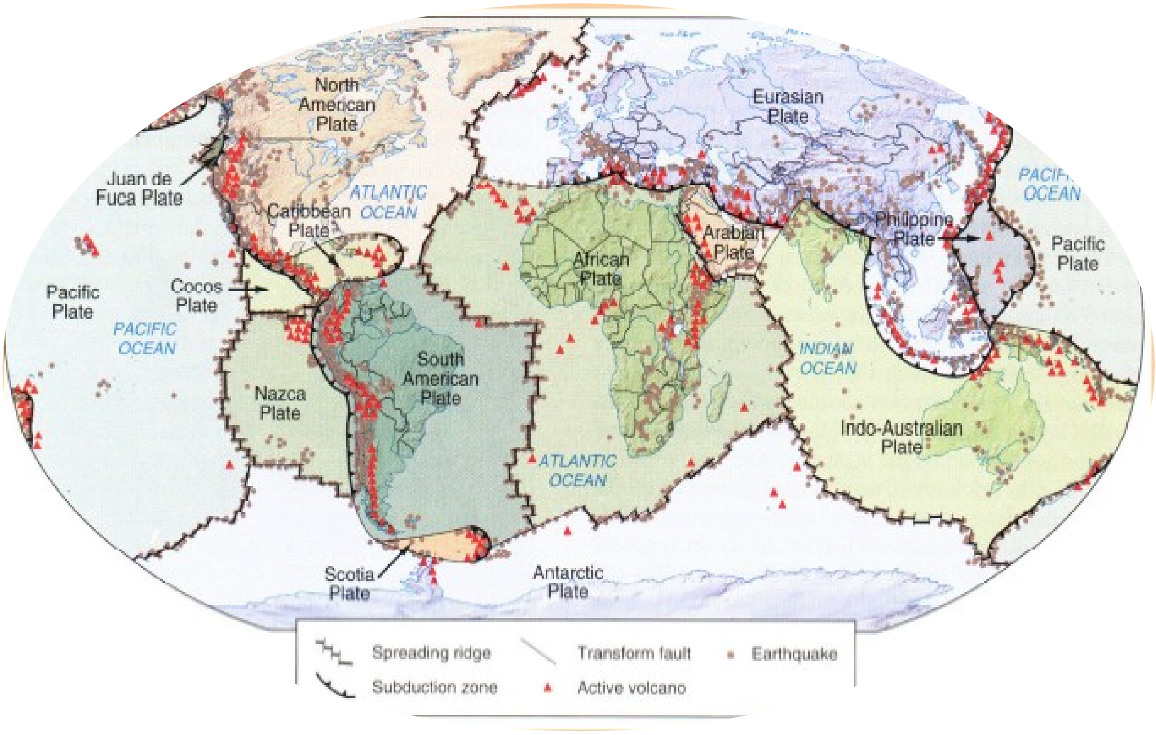
Inner strata

Over time the Earth cools and separates into several different layers. The matter with the highest density (mostly iron) sinks to form Earth’s solid inner core. This inner core becomes enveloped by a less dense mixture of nickel and iron - the outer core. Surrounding the inner and outer core is the mantle (itself divided into several distinct layers), and over the mantle is the Earth’s crust, a thin veneer of rocky material that covers the planet like the cracked, twisted, lumpy crust of an apple pie.

Plates are like giant rafts of the earth's surface which often slide next to, collide with, and are forced underneath other plates. Around the Ring of Fire, the Pacific Plate is colliding with and sliding underneath other plates. This process is known as subduction and the volcanically and seismically active area nearby is known as a subduction zone. There is a tremendous amount of energy created by these plates and they easily melt rock into magma, which rises to the surface as lava and forms volcanoes.

Theory

Plate tectonics is the main current theory in Earth Sciences regarding the development of our planet Earth. It is, therefore, appropriate to dedicate some space to explain how the Earth Science community, step by step, has built this theory, from early speculations, through the gathering of proof and severe debates, up to the refinement and quantification, and still ongoing confrontations with alternative ideas.



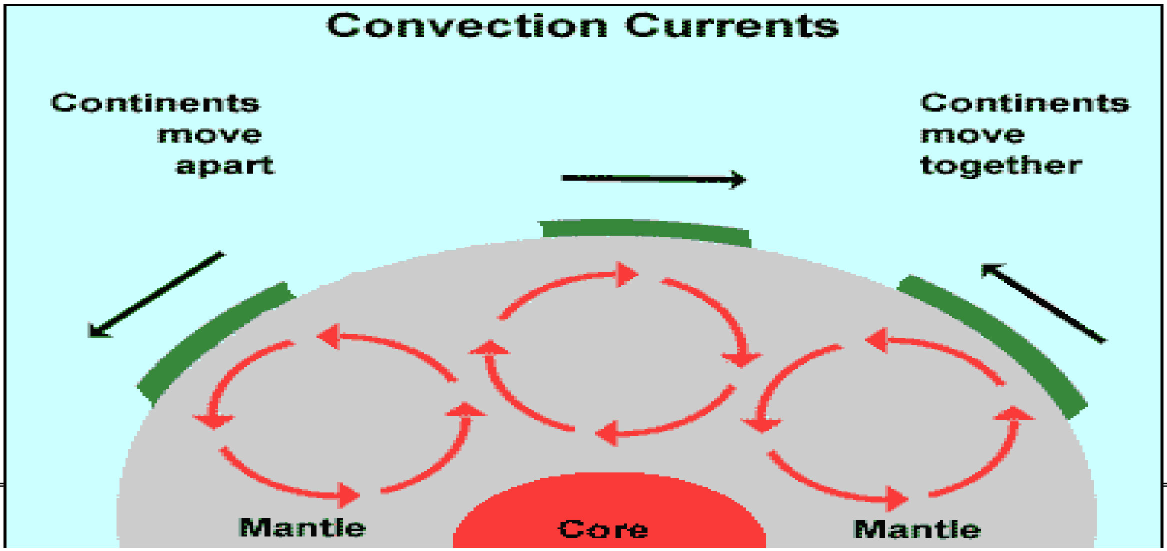
Earth's outer shell, the lithosphere, long thought to be a continuous, unbroken, crust is actually a fluid mosaic of many irregular rigid segments, or plates. Comprised primarily of cool, solid rock 4 to 40 miles thick,* these enormous blocks of Earth's crust vary in size and shape, and have definite borders that cut through continents and oceans alike. *[Oceanic crust is much thinner and more dense than continental, or terrestrial crust].

There are nine large plates and a number of smaller plates. While most plates are comprised of both continental and oceanic crust the giant Pacific Plate is almost entirely oceanic, and the tiny Turkish-Aegean Plate is entirely land. Of the nine major plates, six are named for the continents embedded in them: the North American, South American, Eurasian, African, Indo-Australian, and Antarctic. The other three are oceanic plates: the Pacific, Nazca, and Cocos.

The relative small size of the numerous other plates neither diminishes their significance, nor their impact on the surface activity of the planet. The jostling of the tiny Juan de Fuca Plate, for example, sandwiched between the Pacific and North American Plate near the state of Washington, is largely responsible for the frequent tremors and periodic volcanic eruptions in that region of the country.

How Plates Move

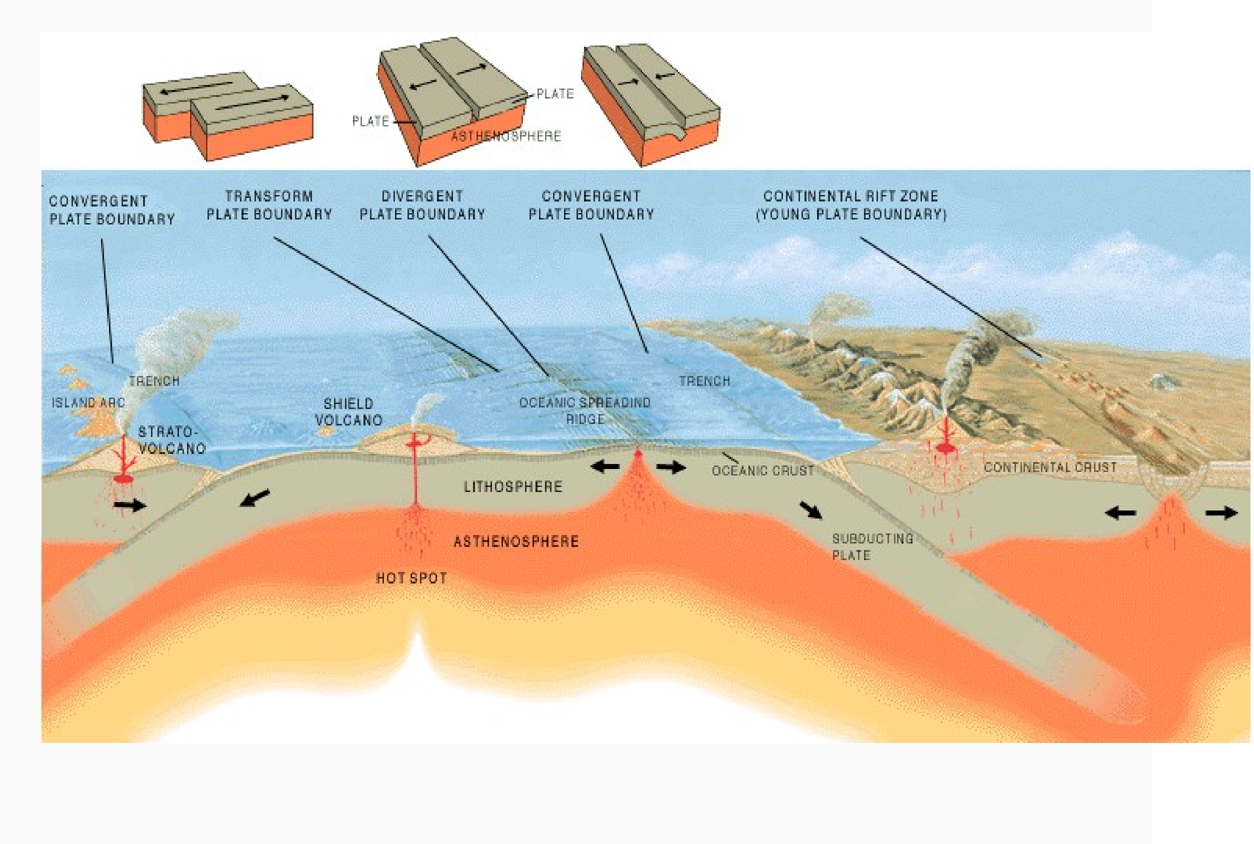
Powered by forces originating in Earth's radioactive, solid iron inner core, these tectonic plates move ponderously about at varying speeds and in different directions atop a layer of much hotter, softer, more malleable rock called the athenosphere. Because of the high temperatures and immense pressures found here, the uppermost part



of the athenosphere is deformed and flows almost plastically just beneath the Earth’s surface. This characteristic of the athenosphere to flow allows the plates to inch along on their endless journeys around the surface of the earth, moving no faster than human fingernails grow. One idea that might explain the ability of the athenosphere to flow is the idea of convection currents. When mantle rocks near the radioactive core are heated, they become less dense than the cooler, upper mantle rocks. These warmer rocks rise while the cooler rocks sink; creating slow, vertical currents within the mantle (these convection currents move mantle rocks only a few centimeters a year). This movement of warmer

and cooler mantle rocks, in turn, creates pockets of circulation within the mantle called convection cells. The circulation of these convection cells could very well be the driving force behind the movement of tectonic plates over the Athenosphere.

Types of plate boundaries



Basically, three types of plate boundaries exist, characterized by the way the plates move relative to each other. They are associated with different types of surface phenomena. The different types of plate boundaries are:

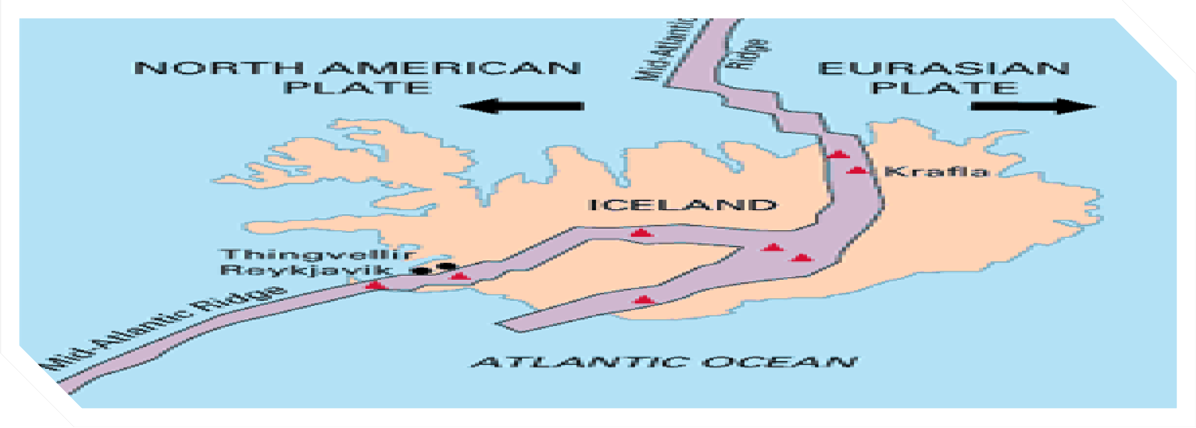
1. Transform boundaries (Conservative) occur where plates slide or, perhaps more accurately, grind past each other along transform faults. The relative motion of the two plates is either sinistral (left side toward the observer) or dextral (right side toward the observer). The San Andreas Fault in California is an example of a transform boundary exhibiting dextral motion.

2. Divergent boundaries (Constructive) occur where two plates slide apart from each other. Mid-ocean ridges (e.g., Mid-Atlantic Ridge) and active zones of rifting (such as Africa's Great Rift Valley) are both examples of divergent boundaries.

3. Convergent boundaries (Subduction boundary) (Destructive) (or active margins) occur where two plates slide towards each other commonly forming either a subduction zone (if one plate moves underneath the other) or acontinental collision (if the two plates contain continental crust). Deep marine trenches are typically associated with subduction zones, and the basins that develop along the active boundary are often called "foreland basins". The subducting slab contains many hydrous minerals, which release their water on heating; this water then causes the mantle to melt, producing volcanism. Examples of this are the Andes mountain range in South America and the Japanese island arc.

Plate Boundaries

There are 3 primary types of Tectonic Plate boundaries: Divergent boundaries; Convergent boundaries; and Transform boundaries. As the giant plates move, diverging [pulling apart] or converging [coming together] along their borders, tremendous energies are unleashed resulting in tremors that transform Earth’s surface. While all the plates appear to be moving at different relative speeds and independently of each other, the whole jigsaw puzzle of plates is interconnected. No single plate can move without affecting others, and the activity of one can influence another thousands of miles away. For example, as the Atlantic Ocean grows wider with the spreading of the African Plate away from the South American Plate, the Pacific sea floor is being consumed in deep subduction trenches over ten thousand miles away. (All graphics courtesy of USGS.org).

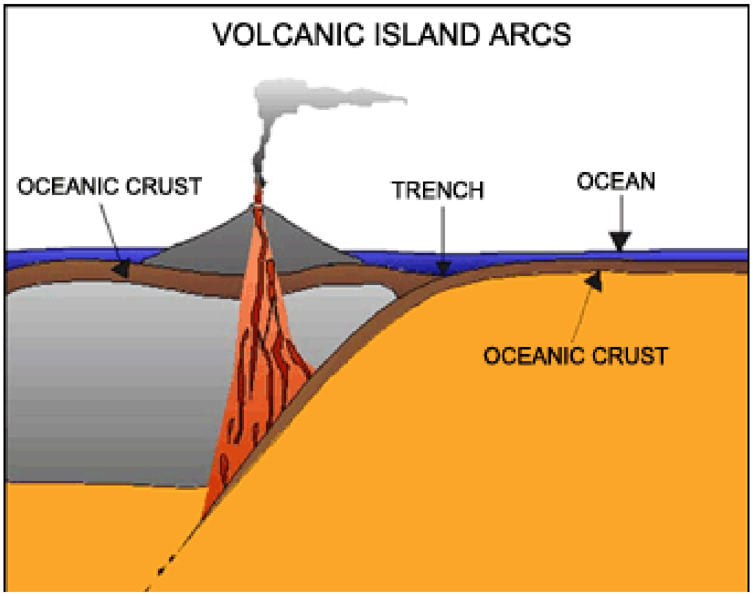


Divergent Boundaries: At divergent boundaries new crust is created plates pull away from each other. Oceans are born and grow wider where plates diverge or pull apart. As seen below, when a diverging boundary occurs on land a 'rift', or separation will arise and over time that mass of land will break apart into distinct land masses and the surrounding water will fill the space between them.

Iceland offers scientists a natural laboratory for studying - on land - the processes that occur along submerged parts of a divergent boundary. Iceland is splitting along the Mid-Atlantic Ridge - a divergent boundary between the North American and Eurasian Plates. As North America moves westward and Eurasia eastward, new crust is created on both sides of the diverging boundary. While the creation of new crust adds mass to Iceland on both sides of the boundary, it also creates a rift along the boundary. Iceland will inevitably break apart into two separate land masses at some point in the future; as the Atlantic waters eventually rush in to fill the widening and deepening space between.

Convergent Boundaries: Here crust is destroyed and recycled back into the interior of the Earth as one plate dives under another. These are known as Subduction Zones - mountains and volcanoes are often found where plates converge. There are 3 types of convergent boundaries: Oceanic-Continental Convergence; Oceanic-Oceanic Convergence; and Continental-Continental Convergence.

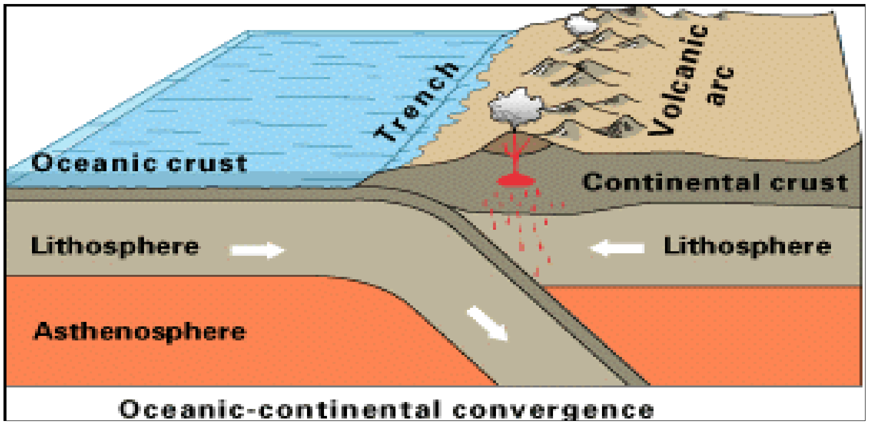
Subduction Zones



When two oceanic plates collide, the younger of the two plates, because it is less dense,* will ride over the edge of the older plate. *[Oceanic plates grow more dense as they cool and move further away from the Mid-Ocean Ridge].

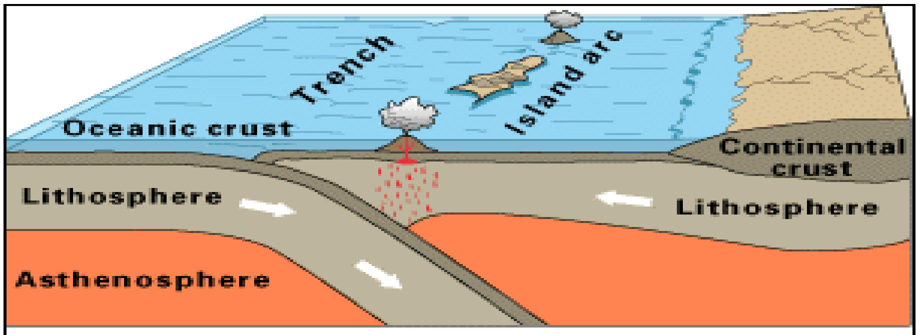
The older, heavier plate bends and plunges steeply through the athenosphere, and descending into the earth, it forms a trench that can be as much as 70 miles wide, more than a thousand miles long, and several miles deep. The Marianas Trench, where the enormous Pacific Plate is descending under the leading edge of the Eurasian Plate, is the deepest sea floor in the world. It curves northward from near the island of Guam and its bottom lies close to 36,000 feet below the surface of the Pacific Ocean.

Oceanic-Continental Convergence



When an oceanic plate pushes into and subducts under a continental plate, the overriding continental plate is lifted up and a mountain range is created. Even though the oceanic plate as a whole sinks smoothly and continuously into the subduction trench, the deepest part of the subducting plate breaks into smaller pieces. These smaller pieces become locked in place for long periods of time before moving suddenly and generating large earthquakes. Such earthquakes are often accompanied by uplift of the land by as much as a few meters.

Oceanic-Oceanic Convergence

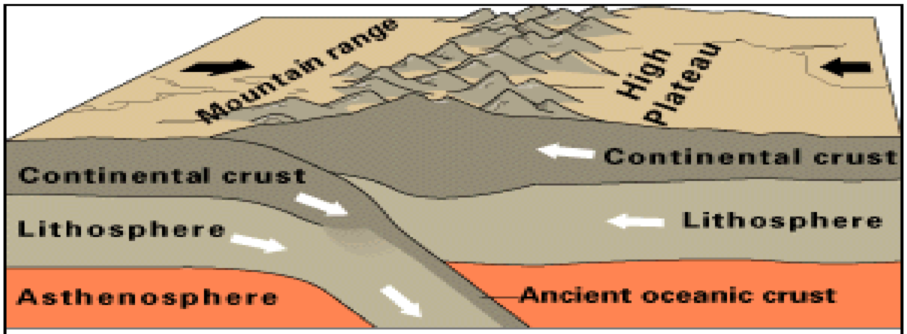


Oceanic-oceanic convergence

When two oceanic plates converge one is usually subducted under the other and in the process a deep oceanic trench is formed. The Marianas Trench, for example, is a deep trench created as the result of the Phillipine Plate subducting under the Pacific Plate.

Oceanic-oceanic plate convergence also results in the formation of undersea volcanoes. Over millions of years, however, the erupted lava and volcanic debris pile up on the ocean floor until a submarine volcano rises above sea level to form an island volcano. Such volcanoes are typically strung out in chains called island arcs.

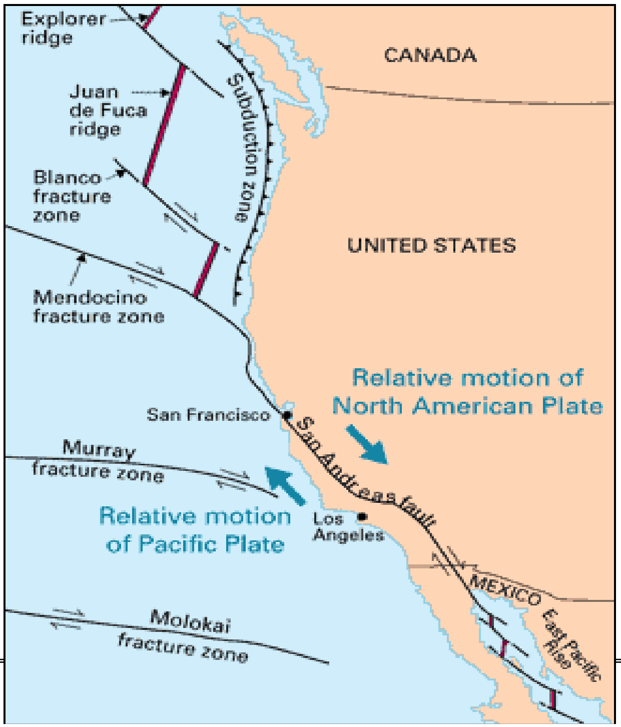
Continental-Continental Convergence



Continental-continental convergence

When two continents meet head-on, neither is subducted because the continental rocks are relatively light and, like two colliding icebergs, resist downward motion. Instead, the crust tends to buckle and be pushed upward or sideways. The collision of India into Asia 50 million years ago caused the Eurasian Plate to crumple up and override the Indian Plate. After the collision, the slow continuous convergence of the two plates over millions of years pushed up the Himalayas and the Tibetan Plateau to their present heights. Most of this growth occurred during the past 10 million years.

Most transform faults are found on the ocean floor. They commonly offset active spreading ridges, producing zig-zag plate margins, and are generally defined by shallow earthquakes. A few, however, occur on land. The San Andreas fault zone in California is a transform fault that

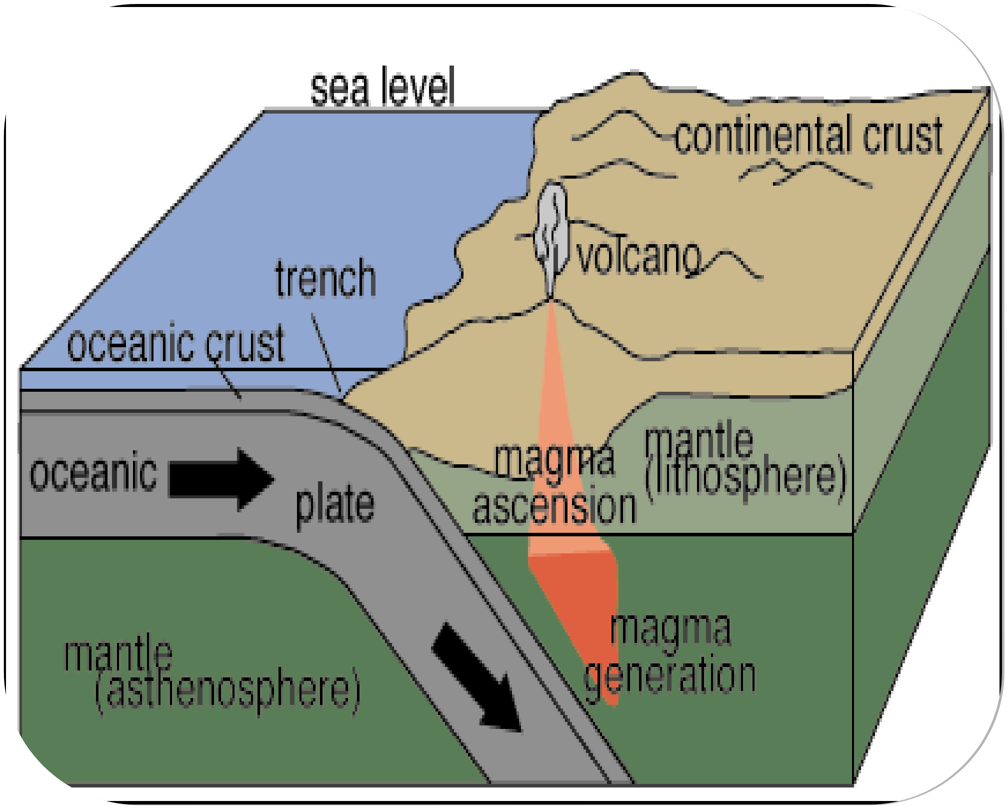


connects the East Pacific Rise, a divergent boundary to the south, with the South Gorda -- Juan de Fuca -- Explorer Ridge, another divergent boundary to the north. The San Andreas is one of the few transform faults exposed on land. The San Andreas fault zone, which is about 1,300 km long and in places tens of kilometers wide, slices through two thirds of the length of California. Along it, the Pacific Plate has been grinding horizontally past the North American Plate for 10 million years, at an average rate of about 5 cm/yr. Land on the west side of the fault zone (on the Pacific Plate) is moving in a northwesterly direction relative to the land on the east side of the fault zone (on the North American Plate).

Trench Flipping

If the descending oceanic plate is carrying a continent, the less dense continental material cannot sink, so it dives into the trench behind the leading oceanic crust until it gets stuck.

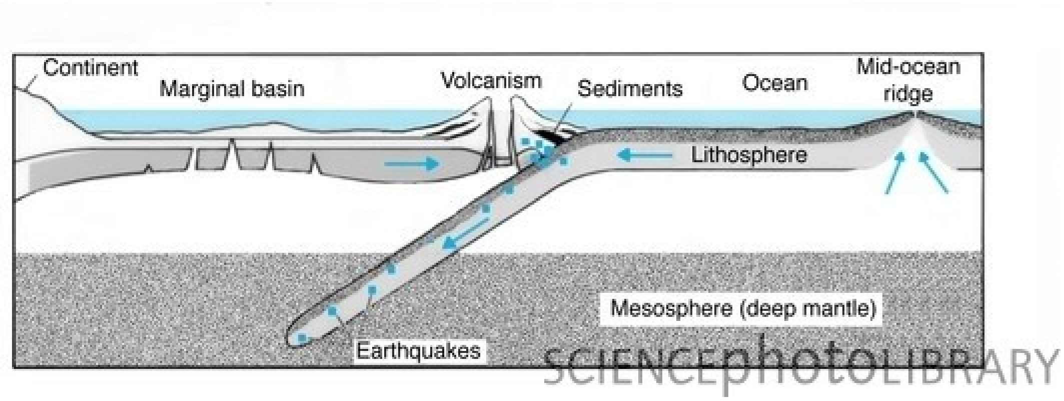
This crumples its leading edge into folded mountains and causes some of the oceanic crust of the overlying plate to be deposited on top of the continent. Pressure steadily builds up until the trench “flips,” and the previously overriding oceanic plate dives under the continental crust. This could explain why most ocean trenches are found along the edges of continents.



If a trench has flipped because of the arrival of a continent, and the newly subducted plate also carries a continent, a collision of land masses is unavoidable. When this happens, subduction terminates along the collision zone, the trench disappears, and the continents collide, resulting in the birth of a new mountain range.

Sometimes an entire plate can disappear if the plates’ leading edge is being consumed in a subduction trench faster than new crust is being added at the ridge on its trailing edge. When this happens, the ridge slowly moves toward the trench and the whole plate is eventually drawn down into the mantle, causing a global rearrangement of other plates and their borders.

Subduction zones occur when dense oceanic plates are forced under less dense continental plates that ride over the top.



At subduction zones there are strong earthquakes. Water from the oceans is taken down, and combined with magma, causes dangerously explosive volcanic eruptions. In 1883 **Krakatau** in Java exploded. The mountain was destroyed. 21 km^3 of rock was ejected from the volcano, and the explosion was considered to be equivalent to a 200 megatons nuclear bomb. The explosion was heard 5000 km away. Some archaeologists think that an earlier eruption of Krakatau led to the dark ages

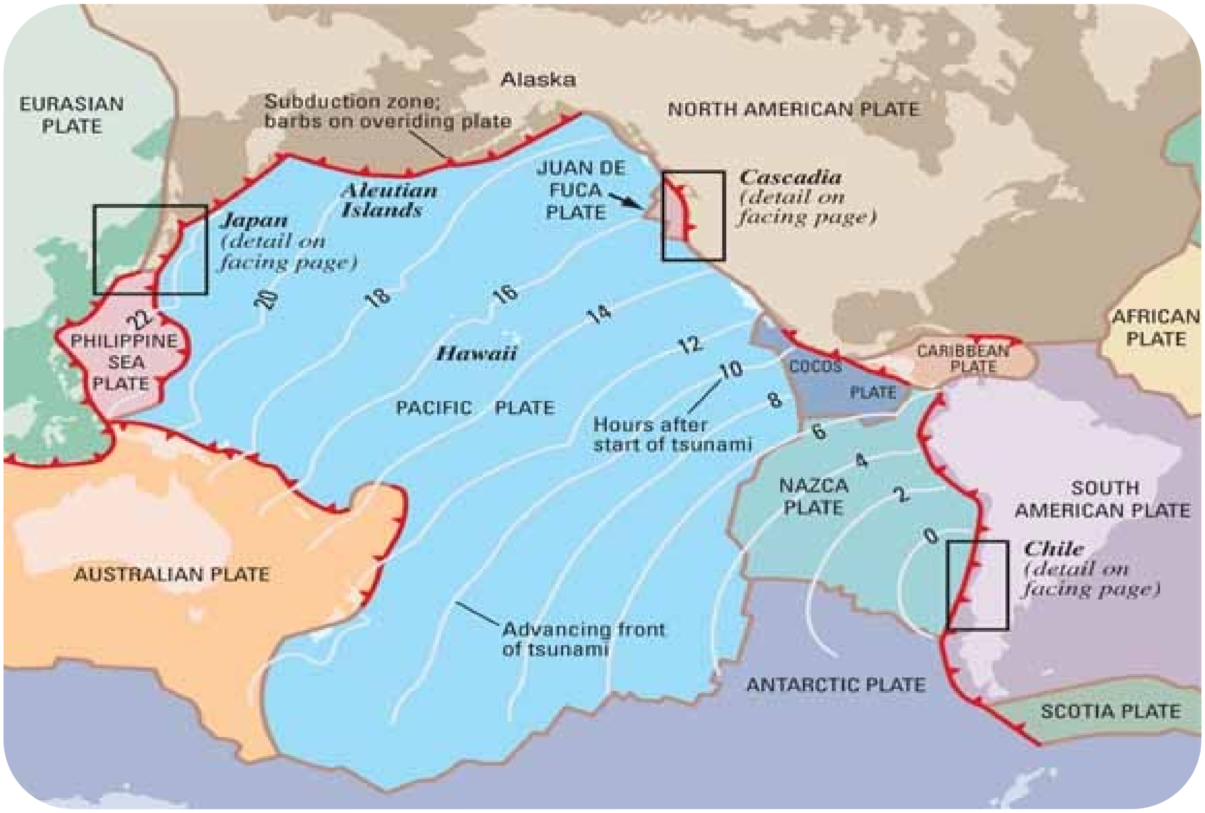
On 9 June 1994, a magnitude-8.3 earthquake struck about 320 km northeast of La Paz, Bolivia, at a depth of 636 km. This earthquake, within the subduction zone between the Nazca Plate and the South American Plate, was one of deepest and largest subduction earthquakes recorded in South America. Fortunately, even though this powerful earthquake was felt as far away as Minnesota and Toronto, Canada, it caused no major damage because of its great depth.

The 1960 Tsunami and the Earthquake in Chile That Caused It

Most of the events described in this book were caused by a series of waves widely known as the “1960 Chilean tsunami.” The tsunami was a result of the largest earthquake ever measured (magnitude 9.5). This quake occurred along the coast of Chile on May 22, 1960.

In Chile, the earthquake and the tsunami that followed took more than 2,000 lives and caused property damage estimated at $550 million (1960 dollars). From Chile the tsunami radiated outward, killing 61 people in Hawaii and 122 in Japan.

The 1960 Chile earthquake ruptured a fault zone along which a slab of sea floor is descending, or “subducting,” beneath the adjacent South American Continent. Such “subduction zones” are formed where two of the tectonic plates that make up the Earth’s outer shell meet. Earthquakes occur when the fault ruptures, suddenly releasing built-up energy. During the 1960 Chile earthquake, the western margin of the South American Plate lurched as much as 60 feet relative to the subducting Nazca Plate, in an area 600 miles long and more than 100 miles wide.



Case study

Earthquakes and tsunamis

The strains caused by plate convergence in subduction zones cause at least three different types of earthquakes. Earthquakes mainly propagate in the cold subducting slab and define the Wadati-Benioff zone. Seismicity shows that the slab can be tracked down to the upper mantle - lower mantle boundary (~ 600 km depth).

Nine out of the ten largest earthquakes to occur in the last 100 years were subduction zone events. This includes the 1960 Chilean Earthquake, which at M 9.5 was the largest earthquake ever recorded. The subduction of cold oceanic crust into the mantle depresses the local geothermal gradient and causes a larger portion of the earth to deform in a more brittle fashion than it would in a normal geothermal gradient setting. Because earthquakes can only occur when a rock is deforming in a brittle fashion, subduction zones can create large earthquakes. If such an earthquake causes rapid deformation of the sea floor, there is potential for tsunamis, such as the earthquake caused by subduction of the Indo-Australian Plate under the Eurasian Plate on December 26, 2004 thatdevastated the areas around the Indian Ocean. Small tremors that create small, non-damaging tsunamis occur frequently.

Outer rise earthquakes occur when normal faults oceanward of the subduction zone are activated by flexture of the plate as it bends into the subduction zone. The Samoa earthquake of 2009 is an example of this type of event. Displacement of the sea floor caused by this event generated a 6m tsunami in nearby Samoa.

Anomalously deep events are a characteristic of subduction zones which produce the deepest earthquakes on the planet. Earthquakes are generally restricted to the shallow, brittle parts of the crust, generally at depths of less than 20 km. However, in subduction zones, earthquakes occur at depths as great as 700 km. These earthquakes define inclined zones of seismicity known as Wadati-Benioff zones, after the scientists who discovered them, which trace the descending lithosphere. Seismic tomography has helped detect subducted lithosphere in regions where there are no earthquakes. Some subducted slabs seem not to be able to penetrate the major discontinuity in the mantle that lies at a depth of about 670 km, whereas other subducted oceanic plates can penetrate all the way to the core-mantle boundary. The great seismic discontinuities in the mantle - at 410 and 670 km depth - are disrupted by the descent of cold slabs in deep subduction zones.

Subduction zones are important for several reasons:

1. Subduction Zone Physics: Sinking of the oceanic lithosphere (sediments + crust + mantle), by contrast of density between the cold and old lithosphere and the hot asthenospheric mantle wedge, is the strongest force (but not the only one) needed to drive plate motion and is the dominant mode of mantle convection.

1. Subduction Zone Chemistry: The subducted sediments and crust dehydrate and release water-rich (aqueous) fluids into the overlying mantle, causing mantle melting and fractionation of elements between surface and deep mantle reservoirs, producing island arcs and continental crust.

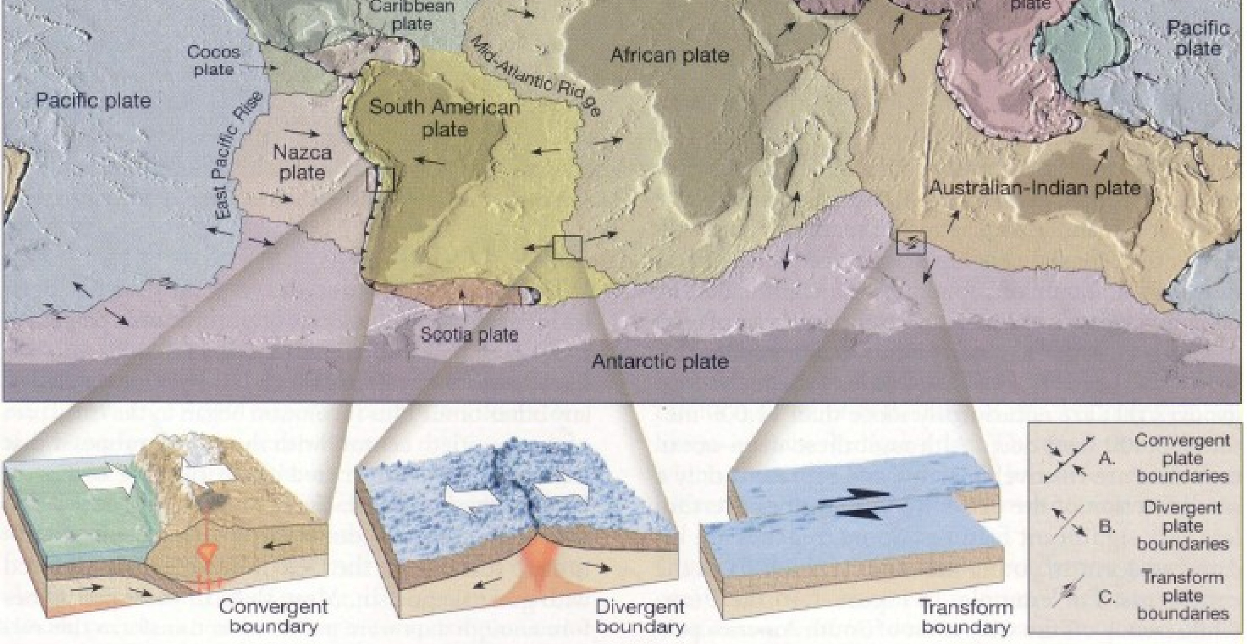
2. Subduction zones drag down subducted oceanic sediments, oceanic crust, and mantle lithosphere that interact with the hot asthenospheric mantle from the overriding plate to produce calc-alkaline series melts, ore deposits, and continental crust.

Subduction zones have also been considered as possible disposal sites for nuclear waste, where the action would carry the material into the planetary mantle, safely away from any possible influence on humanity or the surface environment, but this method of disposal is currently banned by international agreement.

The 1960 Valdivia earthquake or Great Chilean earthquake (Spanish: Gran terremoto de Chile/Valdivia) of 22 May 1960 is to date the most powerfulearthquake ever recorded on Earth, rating 9.5 on the moment magnitude scale. It occurred in the afternoon (19:11 GMT, 14:11 local time) and its resultingtsunami affected southern Chile, Hawaii, Japan, the Philippines, eastern New Zealand, southeast Australia, and the Aleutian Islands in Alaska.

The earthquake was a megathrust earthquake resulting from the release of mechanical stress between the subducting Nazca Plate and the South American Plate, on the Peru-Chile Trench. The focus was relatively shallow at 33 km, considering that earthquakes in northern Chile and Argentina may reach depths of 70 km. Subduction zones are known to produce the strongest earthquakes on earth as their particular structure allows more stress to build up before energy is released.

Subduction zones are the location of very strong earthquakes, which occur because the action of the down going slab interacts with the overriding slab. The "Ring of Fire" around the margins of the Pacific Ocean is due precisely to the subduction zones found around the edges of the Pacific plate. Subduction also is the cause of the volcanic activity in places like Japan: as the down going slab goes deeper beneath the overriding plate, it becomes hotter and hotter because of its proximity to the mantle. This causes the slab to melt and form


Caribbean plate
Cocos plate
Pacific plate
Mid-Atlantic Ridge
African plate
Pacific plate
South American plate
East Pacific Rise
Nazca plate
Australian-Indian plate
Scotia plate
Antarctic plate
Convergent boundary
Divergent boundary
Transform boundary
A. Convergent plate boundaries
B. Divergent plate boundaries
C. Transform plate boundaries

Discussion

Convergent boundary and subduction boundary are the same but just different names and here are some examples for subduction boundaries:

Mount St Helen - Subduction boundary eruption

Vesuvius- Subduction boundary

Krakatau - Subduction boundary

Crater lake- Subduction boundary

We mentioned the type of each boundary for each example because some of the examples got more than one boundary.

The 2004 Indian Ocean earthquake was an undersea megathrust earthquake that was caused by subduction and triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean, killing over 230,000 people in fourteen countries, and inundating coastal communities with waves up to 30 meters (100 feet) high. It was one of the deadliest natural disasters in recorded history. Indonesia was the hardest hit, followed by Sri Lanka, India, and Thailand.

The 2011 Tōhoku earthquake and tsunami, this earthquake occurred where the Pacific Plate is subducting under the plate beneath northern Honshu; which plate is a matter of debate amongst scientists. The Pacific plate, which moves at a rate of 8 to 9 cm (3.1 to 3.5 in) per year, dips under Honshu's underlying plate releasing large amounts of energy. This motion pulls the upper plate down until the stress builds up enough to cause a seismic event. The break caused the sea floor to rise by several meters. A quake of this magnitude usually has a rupture length of at least 480 km (300 mi) and generally requires a long, relatively straight fault surface. Because the plate boundary and subduction zone in the area of the rupture is not very straight, it is unusual for the magnitude of an earthquake to exceed 8.5; the magnitude of this earthquake was a surprise to some seismologists.

Conclusion

Subduction a geological process in which one edge of a crustal plate is forced sideways and downward into the mantle below another plate

A subduction zone is a convergent boundary where two tectonic plates collide. Plates are large, dense masses in the crust of the earth, the lithosphere, that float on top of liquefied rock in the asthenosphere. They are constantly shifting and moving, so when they subduct, one pushes beneath the other. Subduction zones create geologic formations such as mountain ranges, ocean trenches, and island arcs, as well as phenomena like earthquakes and volcanoes.

Tectonic plates are categorized as either oceanic plates that have large bodies of water above them or continental plates that support land. Geologists have learned about how subduction zones work by studying earthquakesin seismology and volcanoes in volcanology.

Many of these plates are in competition, either sliding parallel to each other or directly into and on top of each other (called subduction). So metimes, great amounts of tension build up and are suddenly released , causingearthquakes.

Green soapstone is formed from large deposits of talc that occur in subduction zones, where tectonic plates rub against each other. The gradual movement of the plates causes the stone to undergo a chemical change called dynamothermal metamorphism, which re-crystallizes the chemical components of the stone, resulting in a combination of talc, chlorite, dolomite, and magnesite.

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